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V838 Mon and M31-RV: The Stellar Populations Angle

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Abstract. Insight into the origin of unusual events like the eruption of V838 Mon can be obtained from studies of the stellar populations from which they arise. V838 Mon lies in an intriguing region of the Galaxy, toward the warped outer edge of the disk, with significant contributions from the Galactic thick disk and the recently discovered Monoceros tidal stream. The initial distance measures placed V838 Mon in a jumbled region of the Galaxy but the recent shorter distances make it highly likely that V838 Mon was a thin disk star – likely in a spiral arm – consistent with the recent detection of a young cluster in the vicinity. We compare V838 Mon to M31-RV, a red variable that erupted in the bulge of M31 in 1988 and had a peak luminosity and spectral evolution very similar to V838 Mon. Archival HST images show no nebulosity or unusual stars at M31-RV’s projected location. Moreover, the only stellar population in the field is a canonic old bulge population. This indicates that whatever the origin of the red novae, the mechanism is likely independent of age and progenitor mass. In particular, the B3V star seen in V838 Mon is not a necessary part of the eruption mechanism.

1. Introduction

Understanding events like the eruption of V838 Monocerotis can be helped by identifying the population of stars from which they arise. Stellar populations are usually distinct in their age, abundance and kinematics. Quantifying these properties can yield vital information on their component stars. For example, the age of a stellar population indicates the upper limit of main-sequence stellar mass. Associating unusual stars with distinct stellar populations can be particularly useful in a case like V838 Mon where knowledge of the progenitor and/or remnant of the red nova is extremely limited.

Our understanding of the evolution of horizontal branch stars is a classic example of this method. Because some horizontal branch stars can be associated with globular clusters of unique age and abundance, this has allowed constraint on models of horizontal branch evolution.

In this contribution, we examine the stellar populations associated with V838 Mon and a similar nova M31-RV. Our analysis provides important information on these unusual events.

2. Galactic Stellar Populations – A Primer

V838 Mon and M31-RV erupted within the two large spiral galaxies of the Local Group. The stellar populations of the large spirals are extremely complex and overlap in their properties. However, they can be roughly divided into four distinct groups (for a comprehensive treatment of this subject, see Majewski 1993 or Freeman & Bland-Hawthorn 2002). The dominant stellar populations of the Milky Way, and their counterparts in M31, are:

- The Galactic Bulge - the central spheroidal population of old (12 Gyr or globular cluster age), metal-rich ($[Fe/H] \sim -0.3$) stars (McWilliam & Rich 1994; Zoccali et al. 2003) formed in the early fast evolution of the Milky Way. M31's counterpart is very similar (Davidge et al. 2005; Sarajedini & Jablonka 2005) but may be far more extended.

- The Galactic Thin Disk – a planar distribution which dominates the light of the Galaxy. Although disk are best known for their spectacular spiral arms of gas and young stars, their stellar mass is dominated by a broad distribution of populations over a large range of age and abundance. It is rotationally supported, the Milky Way disk having a rotational velocity of 220 km s^{-1} at the solar radius (Casertano et al. 1990). The density distribution is exponential in radius and height above the Galactic midplane (Siegel et al. 2002, hereafter S02). The disk also show evidence of both warping and flaring (Momaney et al. 2006). The counterpart in M31 is broadly similar and also warped (Innanen et al. 1982; Bellazzini et al. 2003).

- The Galactic Thick Disk – a structure similar to the thin disk but intermediate in age (8-10 Gyr), abundance ($[Fe/H] \sim -0.7$) and rotational velocity (Allende-Preito et al. 2006; Casertano et al.). It is less massive but much more extended than the thin disk (S02). The origin of it is controversial. It is unclear if M31 has a population fitting this description (Sarajedini & Van Duyne 2001).

- The Galactic Halo – an extended diffuse spheroid of old metal-poor stars enveloping the Galaxy. The halo may not have a smooth distribution but may be comprised of streams of stars tidally stripped from dwarf galaxies during past mergers (S02 and references therein). M31's halo was thought to be metal-rich but there are indications that its halo is similar to the Milky Way (Guhathakurta et al. 2006). M31's halo is also known to have streams (Ibata et al. 2001).

The critical aspect of these stellar populations is that they are *distinct* in their properties, particularly their spatial distribution. Certain regions of the Milky Way and M31 are dominated by one population or another, making it possible to associate a star with a parent population and reliably impute the parent's properties to it.

3. V838 Mon's Parent Stellar Population

Unfortunately, V838 Mon occupies a particularly confused part of the Galaxy. The third quadrant is known to have multiple spiral arms (Moitinho et al. 2006), a strong warp in the Galactic disk (Momaney et al. 2006) and a stream of halo stars from a disrupted dwarf galaxy (Newberg et al. 2002), which passes through Monoceros before possibly blending with the disk in Canis Major (see, e.g., Martinez-Delgado et al. 2005 and references therein)

There is no *a priori* reason to assume that V838 Mon belongs to any of these populations. The standard assumption, based on its low Galactic latitude, is that it erupted from a thin disk star (or stars). But, as we will show below, there are reasons to be skeptical of this intuitive assessment.

Figure 1 shows a color-magnitude diagram of the V838 Mon field obtained with the McDonald 0.8m telescope. The figure shows the typical "blue edge" of the field stars. This edge usually runs straight up and down, delineating the main-sequence turnoff of the disks and halo. Reddening along the line of sight, however, moves it redward with increasing magnitude.

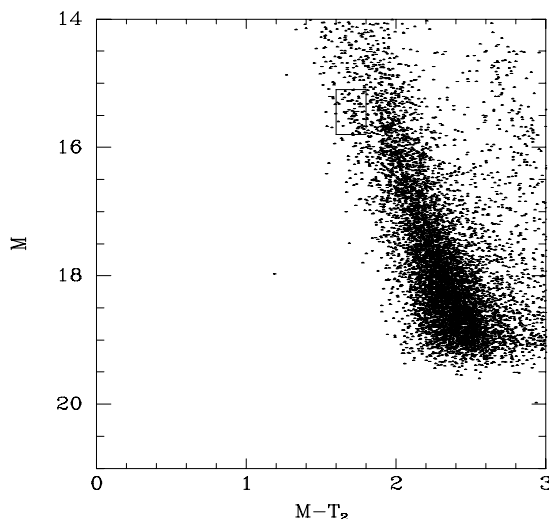


Figure 1. Washington MT_2 photometry of the V838 Mon field. MT_2 is roughly comparable to VI . The box highlights a statistical anomaly along the blue edge of the field stars – a weak young MSTO that traces either the star stream of the Monoceros dwarf galaxy or the Norma-Cygnus spiral arm.

The figure highlights a small bump just beyond the blue edge – an apparently young main-sequence turnoff (detected primarily in a statistical test). This "blue plume" has been used to trace the tidal stream of the merging dwarf galaxy in the third quadrant (Bellazzini et al. 2004). However, Carraro et al. (2006) have shown that the blue plume traces the Norma-Cygnus spiral arm better than it does the merging dwarf. This would be a strong indicator that V838 Mon's position on the sky is coincident with a spiral arm.

Kaminsky & Pavlenko (2005) indicated an iron abundance for V838 of $[Fe/H] = -0.4$. This is a bit rich for this region of the Galaxy (Munari et al. 2005) but within the range of abundances known in either the thin or thick disk.

V838's position in dynamical phase space (velocity and position) could be a powerful discriminant. We have constructed a simple Galactic model based on the density distributions detailed in S02 and the velocity distributions of Casertano et al. (1990). Figure 2 shows the range of radial velocities and

distance above the Galactic stellar midplane dominated by the canonical stellar populations in this region.¹.

The initial indications of a long distance to V838 Mon (~ 8 kpc - Tytenda 2004; Crause et al. 2005; Munari et al. 2005) were problematic for the inferred stellar populations. Figure 2 shows the location of the nova in $v_{helio} - Z'$ space (cross) assuming a distance of 8 kpc. We can see that V838 Mon's classification is ambiguous. The strong disk warp near V838 Mon would give the nova a Z' height of 770 pc. The left panel of Figure 2 shows that V838 Mon's radial velocity ($v_{helio} \sim 65$ km s⁻¹- Claussen et al. 2005; Deguchi et al. 2005; Kipper et al. 2004) would be near the edge of both the thin and thick disk distribution at this Z' while the right panel shows that about one-third of the stars at this Z' are from the thick disk². The Monoceros star stream is still only moderately constrained but comparison to the model of Penarrubia et al. (2005) shows that V838 Mon's velocity and distance would be toward the edge of their tidal stream (see their figure 8). The height above the plane would be inconsistent with membership, however.

However, the shorter geometric distance of ~ 6 kpc (Sparks, these proceedings) moves V838 Mon to familiar territory (starred point on Figure 2). It would be in the middle of the thin disk velocity distribution and its Z' would be even more dominated (80+%) by the thin disk. The new distance would be also be too close to be a member of the Monoceros stream but could be consistent with membership in a spiral arm.

Perhaps the final clinching evidence has been presented in these proceedings by Asfar & Bond, who show that V838 Mon appears associated not with just one B star but with a small cluster of young blue stars. If these stars are associated with the nova, V838 could not possibly be a member of Monoceros, the thick disk or the halo since none of those populations has stars so young.

In summary, the parent stellar population of V838 Mon was far less clear before this conference. The latest results indicate that the intuitive conclusion about V838 Mon is likely the correct one – it is a part of a spiral arm and therefore arose from one of the youngest populations in the Milky Way.

4. M31-RV: A V838-Mon Clone?

V838 Mon is not the first red nova to erupt in the local group. An identical event was observed in the bulge of M31 in 1988 (Rich et al. 1989, Tomaney & Shafter 1992). The event was brighter than $B \sim 18.5$ (Sharov 1990, 1993; Boschi & Munari 2004) for at least 80 days with maximum bolometric luminosity of $M_{bol} \sim -10$. Unlike classical novae, M31-RV remained cool and red throughout its evolution, with an initial spectrum of an M0 supergiant (Rich et al.) which

¹The ordinate in figure 2 is Z' , the distance from *stellar midplane*. Z' takes into account the Galactic warp as parameterized by Drimmel & Spergel (2001) which reaches its maximum southward extent within 20 degrees of V838 Mon

²The chance may be slightly lower due to the presence of a thin disk flare in the third quadrant (Momaney et al.). On the other hand, as S02 show, the radial distribution of the disks is poorly constrained.

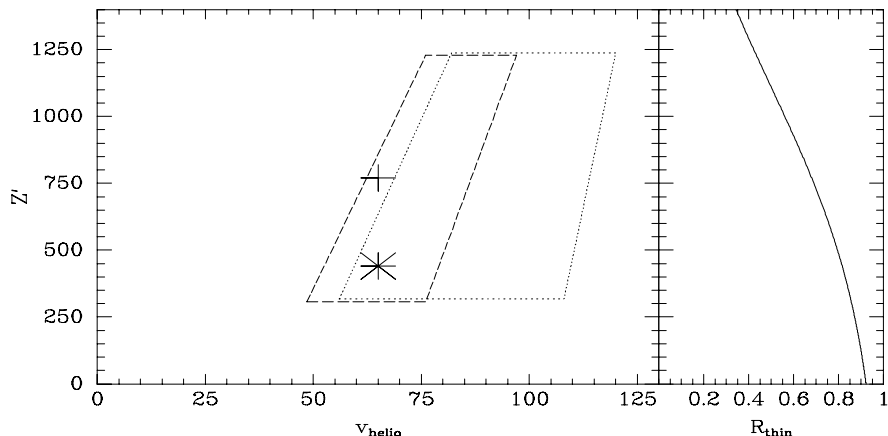


Figure 2. V838 Mon's phase-space location. In the left panel, the abscissa is the heliocentric radial velocity. In the right panel, it is the fraction of stars that are members of the thin disk based on S02 model. The ordinate is Z' , the height above the stellar midplane, taking into account the Galactic Warp. Boxes denote the velocity distribution as function of Z' for the thin disk (dashed) and thick disk (dotted). The cross denotes the initial phase-space location of V838 based on a distance of 8 kpc. The star represents the phase-space location given a 6 kpc distance.

gradually evolved to type M5 and beyond (Mould et al. 1990; Boschi & Munari). Its luminosity, color and evolution are almost identical to that of V838 Mon.

The 1988 event was the only event in the last 50 years (Boschi & Munari) – a silence similar to that seen V838 Mon and V4332 Sgr (Goranskij, these proceedings.)

Little else is known about this rare event. It was, of course, never targeted for observation by HST because the telescope was launched two years later, long after the nova had faded.

In Bond & Siegel (2006), we presented the result of a search of the HST archive for images of the nova site. Although M31-RV was never specifically designated for observation, the region was serendipitously observed by WFPC2 in parallel mode during observations of M31's central black hole. The gem of these observations was a 1999 set of deep F555W-F814W images with the M31-RV site positioned on the Planetary Camera. There have also been recent observations with ACS that have imaged the region in B . Preliminary examination of these frames showed nothing unusual.

The stacked median-combined VI images of the M31-RV site are shown in Figure 3. We see no unusually bright or unusually red stars in the region, no indication of nebulosity or a light echo, which could have expanded to several arc-seconds over the eleven years since the nova.

More insight is provided by the color-magnitude diagram (Figure 4). The diagram, which shows the entire field and a region within 3σ of the estimated

Figure 3. Stacked median images of a 3'' by 3'' area around the M31-RV eruption site. Images are F814W (left) and F555W (right).

M31-RV position, shows only a canonical old bulge population. There is no young population; no spiral arm; no young cluster; no B3V star in the vicinity of M31-RV. In short, the stellar population that produced M31-RV looks nothing like that which produced V838 Mon. M31-RV's remnant, if it is visible at all, is a typical bulge giant.

5. Discussion and Conclusions

An analysis of the stellar populations associated with V838 Mon shows that it likely erupted in a spiral arm from a young, moderately metal-rich population. On the other hand, M31-RV – an event of identical brightness and evolution – erupted in M31's bulge from an old, metal-rich population.

That these identical events could occur in such diverse stellar populations indicates that the mechanism producing the red variables is independent of age – and stellar mass. Any mechanism that requires either an old evolved star or a young unevolved star (such as the B3V star seen in V838 Mon) can not explain both events.

One encouraging note is that two – or possibly three, if we include V4332 Sgr – red novae have erupted in the Local Group within the last twenty years. Although there is no *a priori* reason to assume these events are isotropically distributed in time, it gives hope that more will occur.

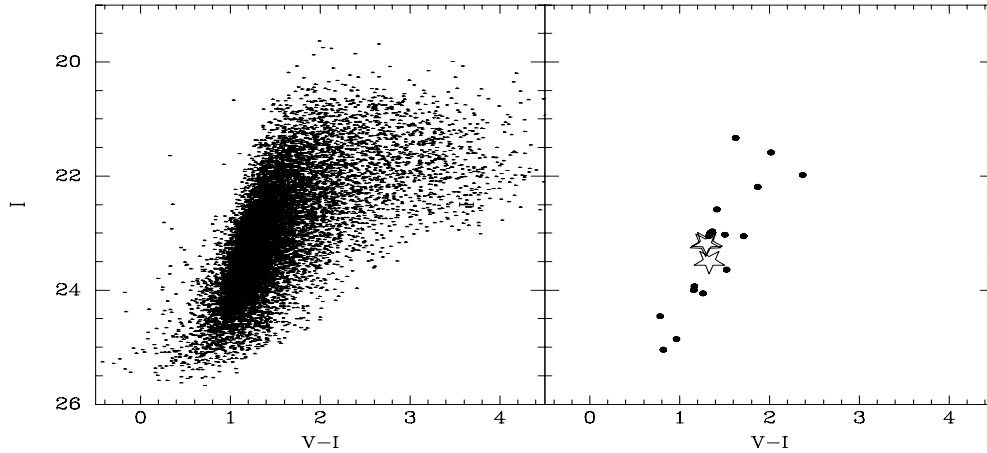


Figure 4. VI images of the region near M31-RV. Photometry of the entire region is shown to the left. The right panel shows stars within 1σ (stars) and 3σ (dots) of the projected M31-RV position.

Our analysis of the stellar populations shows that red variables can occur anywhere in the Local Group. A B3V star is not required. High mass or evolved low-mass stars are not required. The most likely location of a future red novae is the disk or bulge of the two large spiral galaxies, since these contain the bulk of the stellar populations.

Future synoptic surveys of the sky will provide far more information on the progenitors and pre-nova evolution of these rare events. Our understanding of the red novae – whether they produce spectacular light echoes or not – will vastly improve with each new one that appears in the sky.

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Discussion

Sugerman: How reliable is the HST position for M31-RV?

Siegel: We identified the position of M31-RV by directly registering an old image of the RV and the stacked HST image to an intermediate deep I-band 4-meter image. So no assumptions are made about the reliability of HST's pointing.

Sugerman: Given the echo configuration, scattering angles suggest you will not get much echo flux. But since the field is so crowded, you really have to do a difference-image analysis to establish if echoes are missing.

Siegel: I would certainly agree with that, especially since so many years have passed since the eruption event.

Evans: We observed the area around M31RV with the Spitzer IRAC with the aim of getting a follow-up spectrum if we detected it - we didn't.

Siegel: That would indicate that M31-RV has faded in the IR. We'll have to see if V838 Mon has the same evolution of its infrared luminosity.

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